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THE PERFORMANCE OF CABLE BRAIDS AND TERMINATIONS TO LIGHTNING INDUCED TRANSIENTS

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ABSTRACT

The latest specifications detailing the test waveforms for indirect lightning transients as applied to aircraft wiring systems specify very high voltages and currents. Although considerable data exists for measuring cable screen leakage using such methods as Surface Transfer Impedance and Bulk cable Injection there is little data on the likely core transient level that is likely to be induced from these threats. In particular the new Waveform 5 at very high current levels (10kA) is reputed to cause severe cable damage.

A range of representative cables were made with various screen termination techniques and screening levels. These were tested first to determine their relative screening performance and then they were subjected to lightning transient testing to all the specified waveforms. Core voltages were measured for each test.

Tests were also performed on bundles with fewer wires to determine the failure criteria with waveforn 5 and these tests also included Flat Conductor Cables.

The test showed that correctly terminated cable bundles performed well in all the tests and would provide a high level of protection to the electronic systems. The use of overbraides, provided the individual screens are well terminated appears to be un-necessary.

INTRODUCTION

Cable screens are widely used to achieve EMC within aircraft and they can be extremely efficient if properly terminated. Most test used to evaluate their performance, however, use CW techniques over a very wide frequency range, at low amplitude and measure cable screen leakage. Values for the screening efficiency are then determined at various frequencies and these are used for quality assurance and design purposes. The tests are usually performed on short samples (1m) of the cable and results are quoted below resonance frequencies where in reality most leakage would occur.

The situation with a lightning transient is more complicated since the performance of the cable screen in known in frequency domain but not in time domain. It is, of course, relatively easy to calculate the core current waveforms produced by an external pulse of current on the screen using the techniques described by Vance [1]. However, many of the required parameters have to be estimated and are difficult to accurately measure in the real situation. This is certainly true when dealing with a typical aircraft wiring loom that consists of a number of individual screened wires such as twisted pairs. This bundle could then have an outer braid and the termination of all the braids to ground is another significant variable.

The latest indirect lightning transients as detailed in SAE AE4L-87-3 Rev B, DO160C and ABD0007 and describe three basic waveforms which have been well described by Wiles [2]. Although it would be possible to estimate the core current from these waveforms the errors could be very large. The effects of high currents causing local heating and high voltages causing breakdown would of course not be known. It should be remembered that peak currents can now be 10 kAmps with peak voltages of 3.2 kVolts. Further with the oscillatory wave shapes the maximum leakage would occur at resonance frequencies and to evaluate a cable screen it would be essential to determine this frequency.

The lack of any real understanding of the performance of cable braids with these transient levels has resulted in a safety first approach with additional braids being added to cables. It has always been our design aim to produce an optimized design, i.e. a terminated system that adequately meets the threat but at the lowest weight and size. To achieve this one has to build up a library of basic cable and termination performance levels which will also allow one to validate the theoretical calculations.

To this end a series of tests have been carried out on a wide range of cable assemblies with different termination systems. The screening effectiveness of each system was determined using both Surface Transfer Impedance (Zt) and Bulk Cable Injection (BCI) techniques. Each cable was then tested with the specified transients from the SAE AE4L document, waveforms 2,3,4 & 5 at level 5. Additional tests were carried out at the resonance frequencies of each cable, as determined by BCI, with the oscillatory waveform 3. The core voltage was measured in each case and the system examined for physical damage.

A sample using Flat Conductor Cable (FCC) was also added to the trial since there have been a number of doubts over the current carrying capacity of these film bonded copper foil shields.

A final trial was to determine the damage threshold of bundles of screened twisted pairs where each screen was separately terminated to a connector. The number of screened twisted pairs being progressively reduced and the waveform 5 transient injected down the braids. This has the effect of concentrating the current in fewer terminations and will lead to eventual failure.

TEST SAMPLES

The samples were divided into three basic groups, the first was based on screened twisted pair bundles with various termination techniques and the second on screened wire bundles with flat connectors and the third on a Flat Conductor Cable (FCC) structure. The samples in the first group were all 3m long whilst the other groups were 1 m. These groups were also fitted with connectors. The other group whilst having termination fittings where fitted with dummy brass inserts instead of connectors.

The types of termination for the screens of the twisted pairs within the first group where considered essential and three systems were used, first standard pigtails, second an iris cone clamp and thirdly individual ferrules for each twisted pair mounted into a retaining plate (Hexashield). These are illustrated.

Screened Twisted Pair Bundles. This consisted of 20 screened 24 awg twisted pairs machined laid to make a harness. The following samples were made:-

STP/0B/P Cable with no outer screen, wire screens, terminated by pigtail

STP/0B/I Cable with no outer screen, wire screens, terminated by Iris clamp.

STP/0B/H Cable with no outer screen, wire screens, terminated by Hexashield.

STP/1B/P Cable with single outer screen, wire screens, terminated by pigtails.

STP/2B/P Cable with double outer screen, wire screens, terminated by pigtails.

Flat Connector System. This consisted 24 awg Screened Twisted Pairs and the numbers in each harness were 20, 15 and 10. The normal number for such a connector is 20 wires and hence the current level per termination was increased by 33% and 50% above the specified levels. Termination was by a bus-bar that commoned all the screens.

20STP/0B Cable with 20 STP terminated separately, into MTC Connector.

15STP/0B As above but 15 wires.

10STP/0B As above but 10 wires.

Flat Conductor System. Screens consist of film bonded mylar/copper foils. The basic cable consisted of two flat conductor cables with a mylar/copper foil bonded to each and a second foil between the two layers. This gave a total of three screening copper foils and an overall mylar/copper foil was used to screen the complete harness.

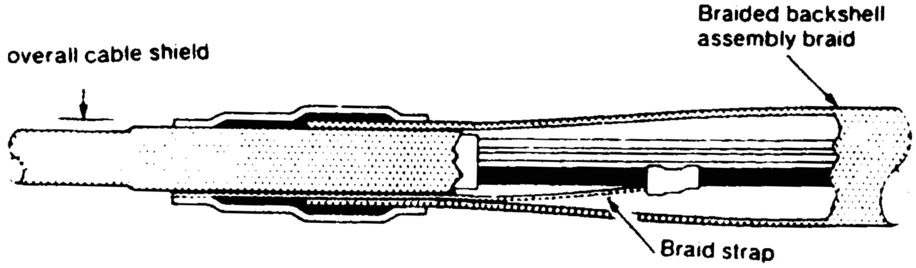
FCC/3F/1B/MTC FCC with three copper foil screens and an outer wrap around foil screen, grounded to MTC connector.

SCREENING PERFORMANCE

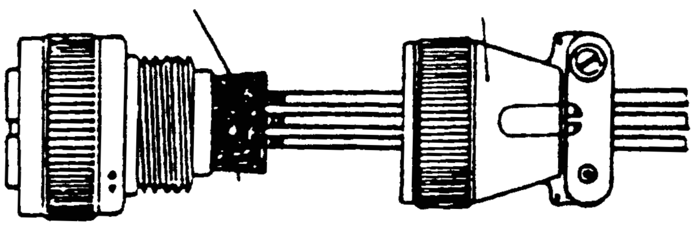
There have been many papers presented that overview methods of measuring Surface Transfer Impedance (Zt) [3,4 & 5] and also Bulk Cable Injection (BCI) [6] and space does not permit detailed description of the techniques. Zt was measured by driving a current down the cable braid (over a ground plane) and measuring the resultant voltage on the central conductors. BCI used an injection coil to generate the screen current and in our tests the resultant voltage on the central conductors recorded. The test set up is, however, unmatched and the upper frequency where the results are still valid for this length of cable is about 10 MHz.

SCREENED TWISTED PAIR TERMINATION TECHNIQUES

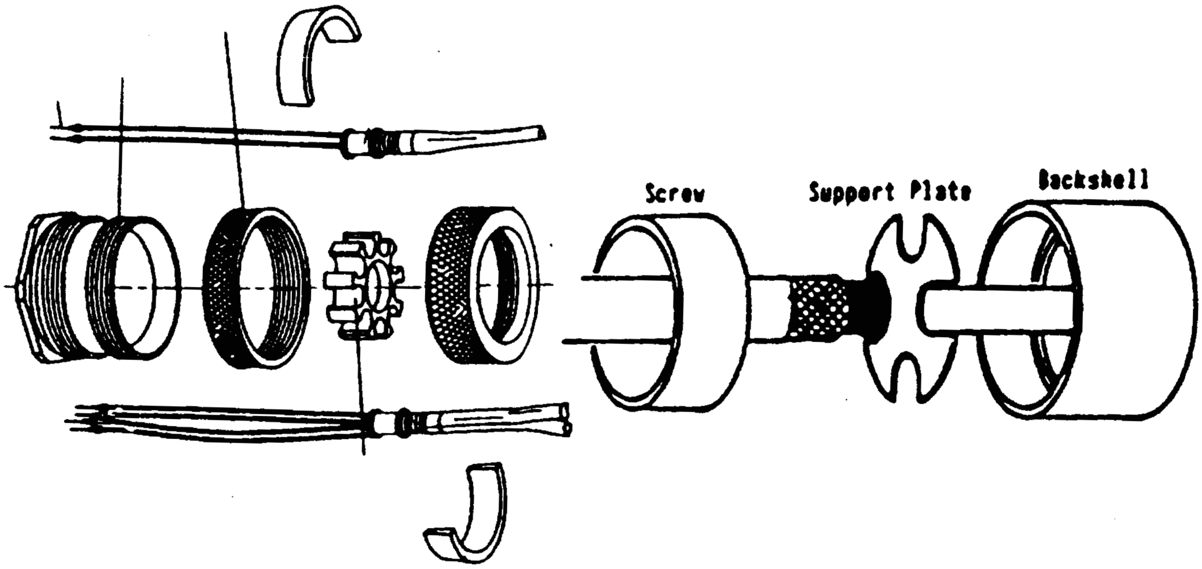
BRAID STRAP OR PIG-TAIL. Each braid of the screened twisted pair is terminated to the overall cable screen.

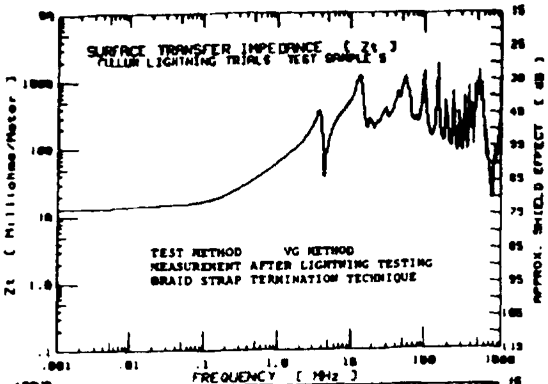


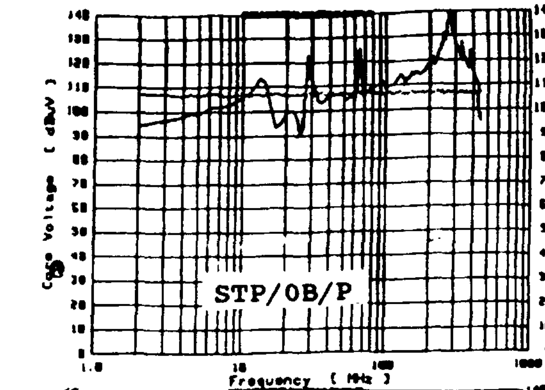
IRIS CLAMP. Each screened twisted pairs braid is combed out and trapped under a spring IRIS and the connector backfitting.

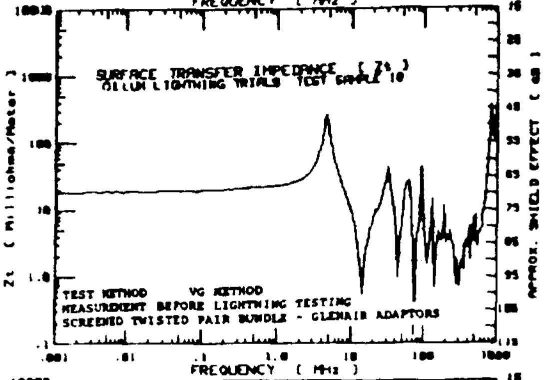


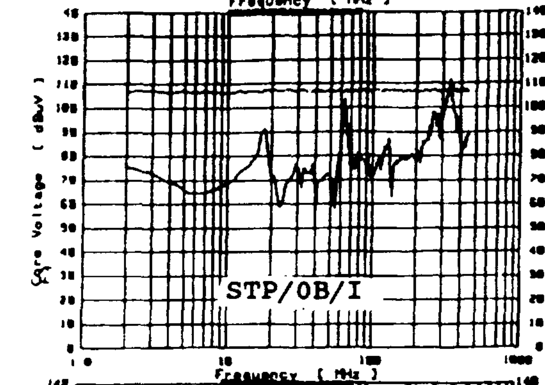
HEXASHIELD TERMINATION. Onto each screened twisted pair braid a metal ferule is terminated with a solder sleeve. Each ferule fits into a metal retaing plate and is secured by a clamp nut.

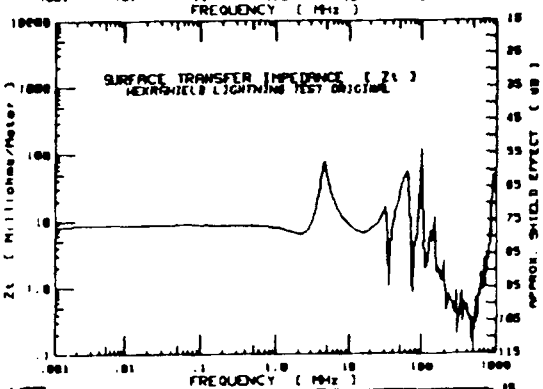


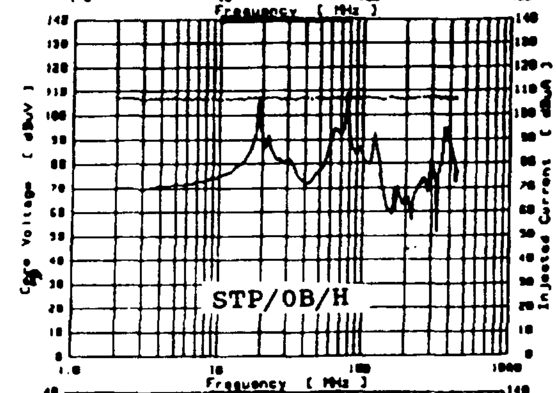

SURFACE TRANSFER IMPEDANCE (Zt)
CULLUM LIGHTNING TRIALS TEST SAMPLE 5
TEST METHOD VG METHOD
MEASUREMENT AFTER LIGHTNING TESTING
BRAID STRAP TERMINATION TECHNIQUE
Zt (Milliohms/Meter)
APPROX. SHIELD EFFECT (dB)
FREQUENCY (MHz)

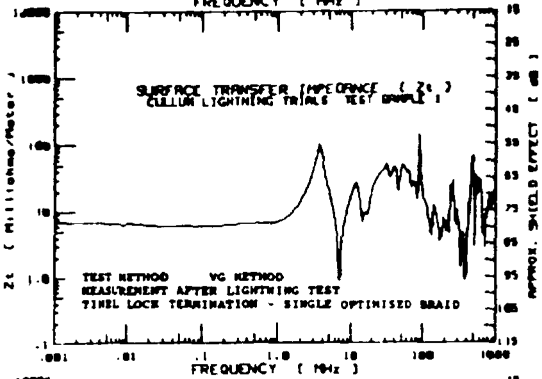

STP/0B/P
Core Voltage (dBuV)
Injected Current (dBuA)
Frequency (MHz)

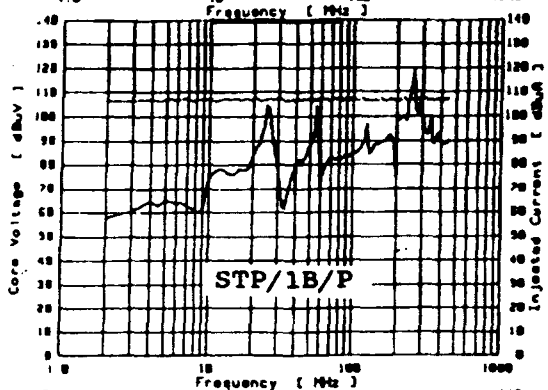

SURFACE TRANSFER IMPEDANCE (Zt)
CULLUM LIGHTNING TRIALS TEST SAMPLE 10
TEST METHOD VG METHOD
MEASUREMENT BEFORE LIGHTNING TESTING
SCREENED TWISTED PAIR BUNDLE - GLENAIR ADAPTORS
Zt (Milliohms/Meter)
APPROX. SHIELD EFFECT (dB)
FREQUENCY (MHz)

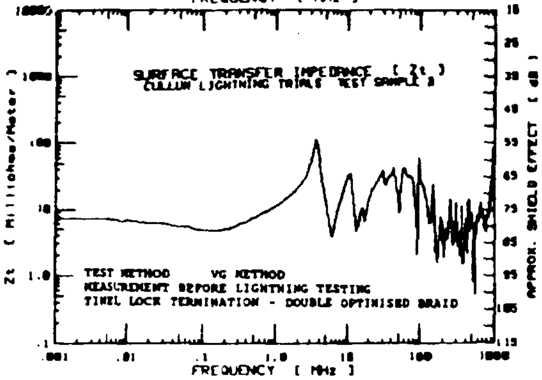

STP/0B/I
Core Voltage (dBuV)
Injected Current (dBuA)
Frequency (MHz)

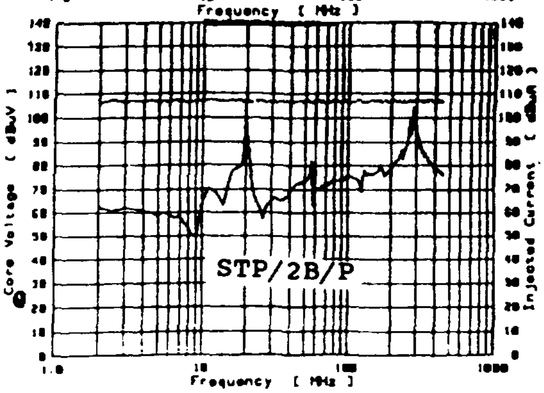

SURFACE TRANSFER IMPEDANCE (Zt)
HEXASHIELD LIGHTNING TEST ORIGINAL
Zt (Milliohms/Meter)
APPROX. SHIELD EFFECT (dB)
FREQUENCY (MHz)


STP/0B/H
Core Voltage (dBuV)
Injected Current (dBuA)
Frequency (MHz)


SURFACE TRANSFER IMPEDANCE (Zt)
CULLUM LIGHTNING TRIALS TEST SAMPLE 1
TEST METHOD VG METHOD
MEASUREMENT AFTER LIGHTNING TEST
TINEL LOCK TERMINATION - SINGLE OPTIMISED BRAID
Zt (Milliohms/Meter)
APPROX. SHIELD EFFECT (dB)
FREQUENCY (MHz)


STP/1B/P
Core Voltage (dBuV)
Injected Current (dBuA)
Frequency (MHz)


SURFACE TRANSFER IMPEDANCE (Zt)
CULLUM LIGHTNING TRIALS TEST SAMPLE 3
TEST METHOD VG METHOD
MEASUREMENT BEFORE LIGHTNING TESTING
TINEL LOCK TERMINATION - DOUBLE OPTIMISED BRAID
Zt (Milliohms/Meter)
APPROX. SHIELD EFFECT (dB)
FREQUENCY (MHz)


STP/2B/P
Core Voltage (dBuV)
Injected Current (dBuA)
Frequency (MHz)

LIGHTNING TESTING

Screened Twisted Pairs (Group 1). The lightning transients were applied to the cables using two techniques as described in the reference [2] and these were Bulk Cable for waveforms 2 and 3 and Ground Injection for waveforms 4 and 5. The number of pulses applied was 5 of each polarity. The test configuration is shown.

Level 5 was used for each transient. The higher frequency waveform 3 oscillatory waveform was tested at 1, 10, 30 and 50MHz as well as the resonant frequency. The first cable resonance as determined from the BCI test was included as this is the frequency of maximum cable leakage.

We were interested in any possible damage that could occur with the very high powered waveform 5 at 10 kAmps and we remeasured the basic screening performance after these tests using both Zt and BCI.

The voltage waveform on the central conductor was recorded. All the central conductors were commoned together in these trials. The termination resistance was 50 Ohms.

The test conditions used were those described in the SAE AE4L-87-3 Rev B 1989 document.

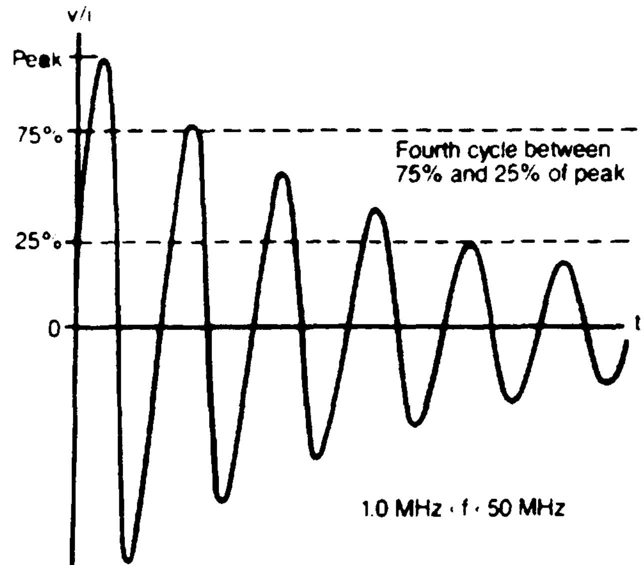
Screened Twisted Pairs with MTC Connectors (Group 2). This trial was intended to determine the number of individual screened wires can be used and still carry the full threat of waveform 5. The test was applied to each of the harnesses until either a total of 10 shots were passed or damage occurred to the sample.

Flat Conductor Cable with MTC Connector (Group 3). This trial was carried out using waveform 5 at 10 kAmps. A total of 10 shots were made and the sample examined for any damage.

Level	Waveforms			
	2	3	4	5
	Vp/Ip	Vp/Ip	Vp/Ip	Vp/Ip
1	50/10	100/4	50/10	N/A
2	125/25	250/10	125/25	N/A
3	300/60	600/24	300/60	300/100
4	750/150	1500/60	750/150	750/1000
5	1600/320	3200/128	1600/320	1600/3000 to 20 000

Vp – Peak Open Circuit Voltage Line-to-Ground
Ip – Peak Short Circuit Current On A Line

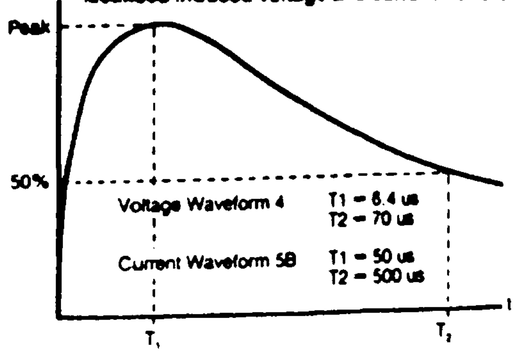
Suggested ETDL Voltage and Current Levels

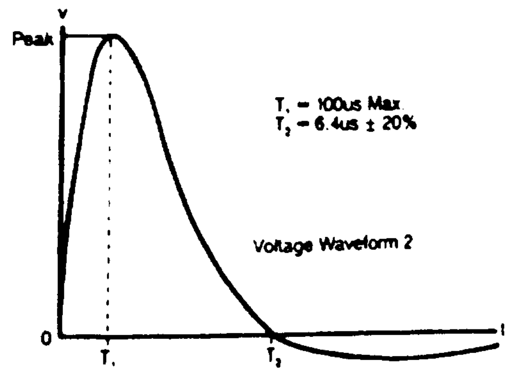


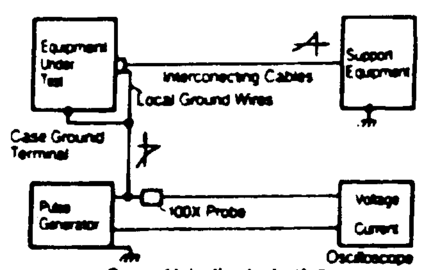
Voltage Waveform 3

Idealised induced voltage and current waveforms

V/I Idealised induced voltage and current waveforms

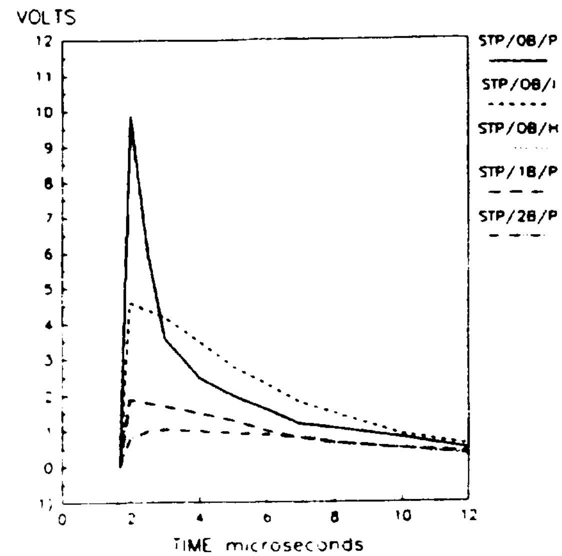


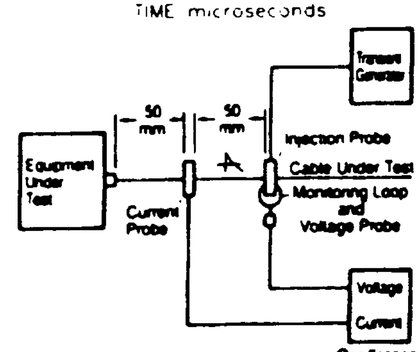




Ground injection test setup

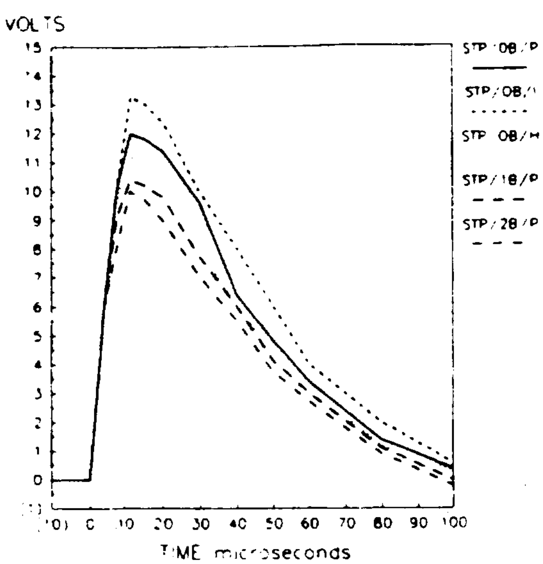
WAVEFORM 2 SHORT PULSE
BULKCABLE INJECTION 320 Amps/6usecs
CABLE CORE VOLTAGE



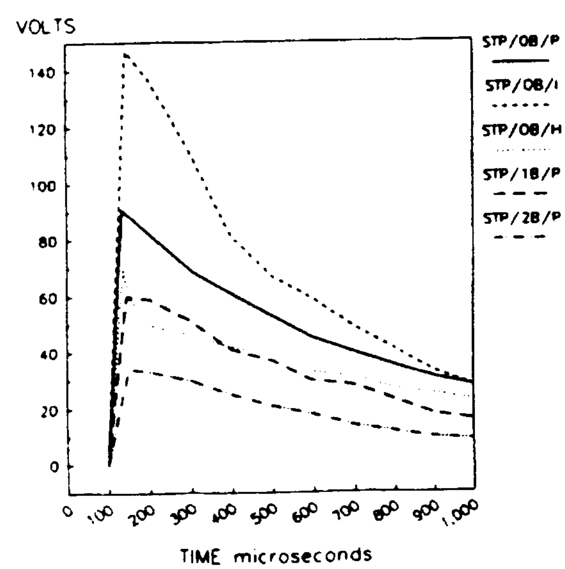


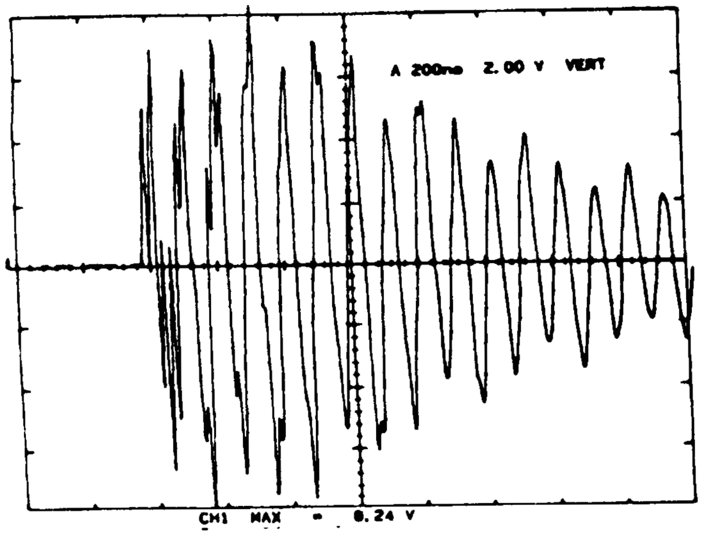
Bulk cable injection test setup

WAVEFORM 4
GROUND POINT INJECTION 320 Amps/70 usecs
CABLE CORE VOLTAGE

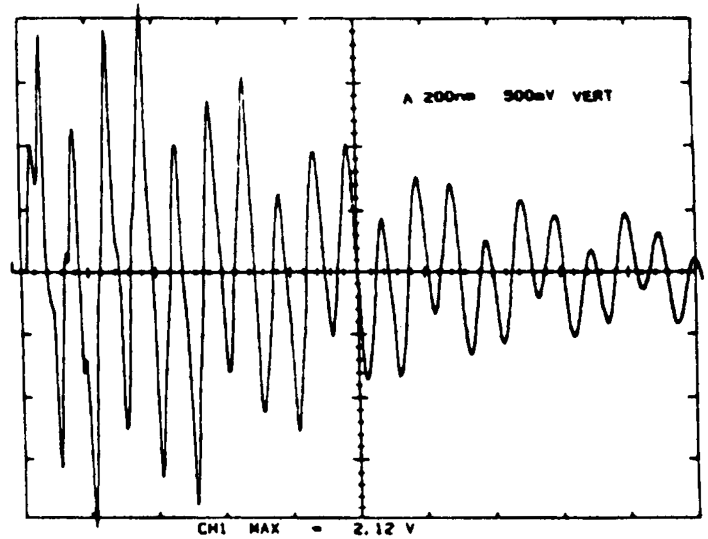


WAVEFORM 5 TEST (LONG PULSE)
GROUND POINT INJECTION 10kAmps/500us
CABLE CORE VOLTAGE

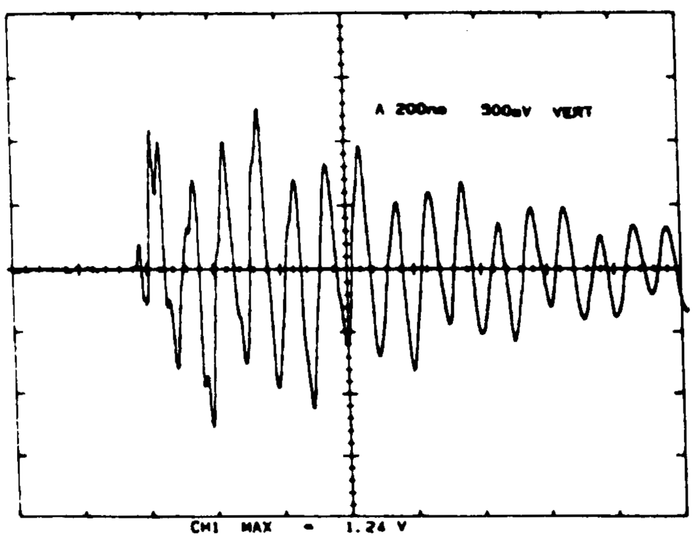




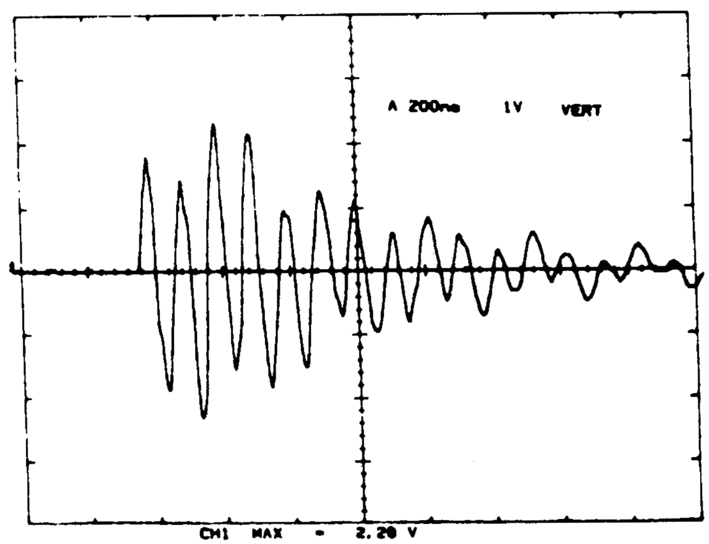
STP/0B/P



STP/0B/I



STP/0B/H



STP/1B/P

TEST RESULTS

Screened Twisted pair Cables (Group 1 Samples).
Cable Leakage. There were two techniques used and these were Surface Transfer Impedance (Zt) and Bulk Cable Injection (BCI) and the test results for both these tests for the Screened Twisted Pair Bundles of the first group of test samples are shown. The BCI current was 250 ma.

Lightning Transient Testing. The waveforms for the voltage waveforms 2,3 and 5 are shown for the first group of samples i.e. the screened twisted pair cables.
The number of waveforms tested of the oscillatory form (Wfm. 3) are too numerous to reproduce and the table gives the peak values, examples are given.

Screened Twisted Pairs with MTC Connectors (Group 2). Each sample was tested a number of times until failure. Samples with 20 and 15 wires passed and that with 10 failed catastrophically after 2 shots. An explosion destroyed the connector backshell and the terminations. The connector termination failing when the current stress level was twice the specified level. Failure was not in the connector or the screened twisted pair but in their interconnection.

Flat Conductor Cable with MTC Connectors. The sample passed the trial and the peak voltage was 57 volts.

PEAK VOLTAGE TRANSIENT DURING PULSE TESTING					
WAVEFORM	STP/0B/P	STP/0B/I	STP/0B/H	STP.1B/P	STP/2B/P
DC Rest mohms	8.7	9.3	6.1	8.0	3.4
Wfm 2 (320A)	9.9	4.4	2.3'	2.0	0.8
Wfm 3 (128A)					
1 MHz	3.8	3.8	1.4	1.6	0.6
10 MHz	8.2	2.1	1.2	2.3	0.7
30 MHz	19.2	15.4	7.1	25.2	11.4
50 MHz	104.0	39.2	5.6	8.6	3.9
Resonance	81.7	33.0	17.9	20.2	19.5
Wfm 4 (320A)	11.7	13.0	10.9	10.2	9.5
Wfm 5 (10kA)	91.0	147.0	70.0	60.0	33.0

CONCLUSIONS

Waveform 5 Tests.

The waveform 5 transient does not appear to pose a threat to aircraft wiring looms. The threat current of 10 kAmps can be carried by both bundles of screened twisted pairs (with as few as 10 wires) and Flat Conductor Cables. Connectors of the MTC design can carry the full threat current without damage. Connector fittings, if the current is localised by having only a few current carrying wires can be damaged with this waveform.

The induced central core voltage can be simply calculated from the DC resistance of the cable and assuming the current is DC. This induced voltage is certainly capable of upsetting or damaging electronics.

Waveform 2 & 4.

Both these waveforms produced double exponential voltage transients of similar but low magnitude. They would be capable of upset in certain signal lines.

Waveform 3.

This transient demonstrated the importance of braid termination. It is well known how bad pigtails are and the effect on cable leakage is clearly seen in the results for Zt and BCI. The cable STP/0B/P, the one where the screens were terminated with pigtails shows very poor performance at high frequency. The termination of the same cable with an "IRIS" type clamp reduces the voltage dramatically whilst the soldered ferule clamped into the metal housing of the HEXASHIELD termination provides outstanding performance.

It can be seen from samples STP/1B/P and STP/2B/P where the pigtail samples have had over-braides put over the cable bundles that the performance is still not as good as a cable with no overall cable screen but good 360^{o} individual screen termination.

General Comment.

The voltage transients were not as severe as first predicted and the effect of the high current waveform 5 did not cause the problems that we had been warned against. In general most screened cable bundles with proper screen termination should provide a high level of protection.
The use of techniques such as Surface Transfer Impedance and Bulk Cable Injection provides useful indications of likely performance but given the inaccuracy of these methods when applied to an unmatched system estimated performance should be treated with caution.

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5 Carter, Int EMC Conference York University 1990.
6 British Defence Standard Def-Stan 59-41 1989.

ACKNOWLEDGEMENT

To the staff at the Culham Lightning Studies Unit for their help in performing the Waveform 5 tests and for their technical advice.